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Abstract

The environment in which research is being conducted and disseminated is undergoing profound change, with new technologies offering new opportunities, changing research practices demanding new capabilities, and increased focus on research performance. A key question facing us today is, are there new opportunities and new models for scholarly communication that could enhance the dissemination of research findings and, thereby, increase the returns to investment in R&D?

Identifying access and efficiency limitations under the subscription-based publishing model that has dominated scientific publishing, this paper explores the potential impacts of enhanced access to research outputs. We develop a modified growth model, introducing 'access' and 'efficiency' into calculating the returns to R&D. Indicative impact ranges are presented for gross expenditure on R&D (GERD) and government expenditure on R&D (GovERD) for all OECD countries. We conclude that there may be substantial benefits to be gained from increased access to research findings, and our preliminary estimates suggest that this may be fertile ground for further policy relevant inquiry.

(Approx. 5,000 words)

Keywords: Growth, Open Access, Productivity, Research and Development (R&D), Returns to R&D, Scholarly Communication, Scientific Publishing.

Introduction

The existing system of scholarly publishing evolved over many years to serve the needs of disciplinary research in specialist institutions in a print-based environment. But the scholarly information environment is now undergoing profound change as a result of new technologies allowing new modes of research dissemination, changing research practices and needs, and increased focus on research performance (Houghton *et al.* 2003; 2004; Van de Sompel *et. al.* 2004; Houghton 2005a; 2005b). As a result, the existing publishing system no longer serves well the needs of researchers for uninhibited access to the research findings of others, or the needs of their funders for cost effective dissemination of findings in order to maximise the economic and social returns to their investment in R&D. A key question facing us today is, are there new opportunities and new models for scholarly communication that could enhance the dissemination of research findings and, thereby, increase the economic and social returns to investment in R&D?

This paper begins with a brief look at the evolution of scientific publishing during the transition from print to online delivery. It then explores the literature on online access opportunities, focusing on two key aspects: *(i)* access constraints under the subscription publishing system, and *(ii)* potential impacts of enhanced access on the efficiency of R&D. The subsequent section explores the potential impacts of enhanced access on users of research outputs in research, industry, government and the wider community. We then develop a modified growth model, introducing 'access' and 'efficiency' as variables influencing the economic and social benefits of R&D, and use it to quantify the potential impacts of enhanced access on returns to R&D. Results are presented in Table 2, which shows the recurring annual gain from a given percentage change in both accessibility and efficiency for gross expenditure on R&D (GERD) and government expenditure on R&D (GovERD) for all OECD countries, with impact ranges based on rates of return to R&D of 25% to 75%, and 1% to 10% increases in accessibility and efficiency.

The evolution of scholarly communication

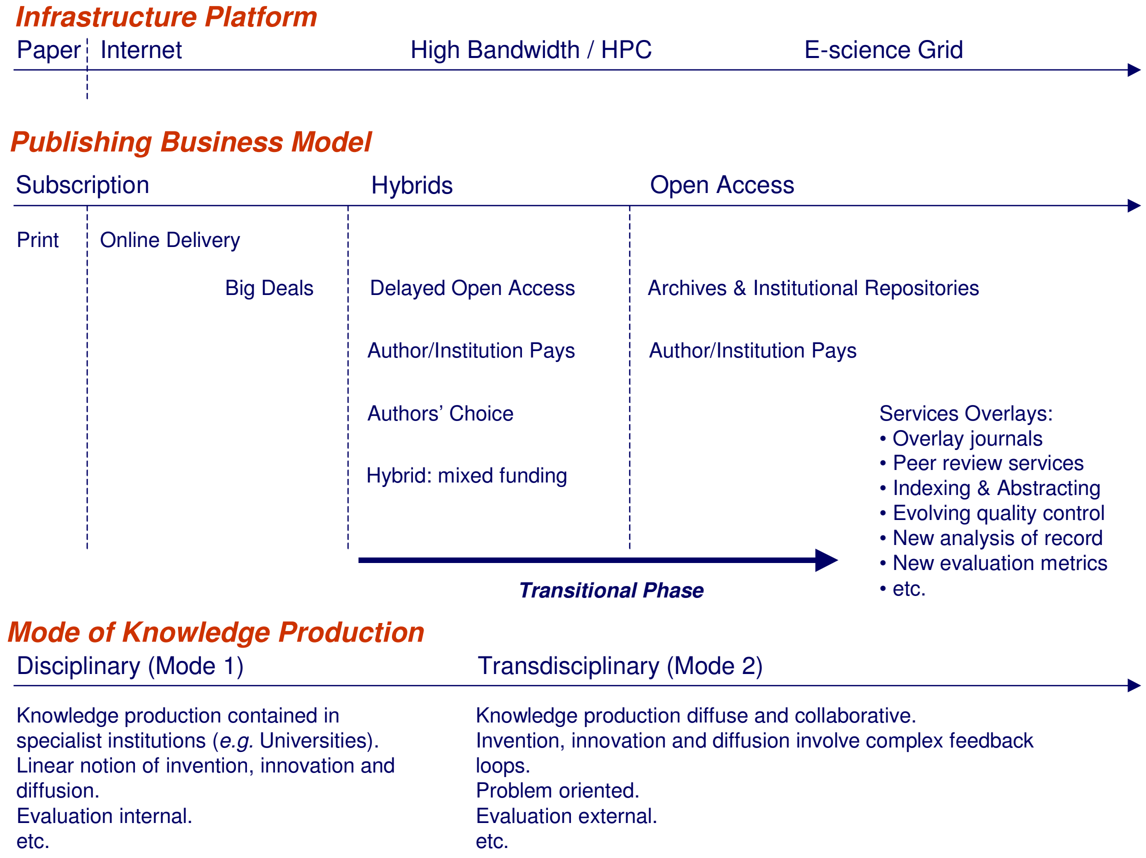
The scientific publishing and the scholarly communication system is evolving. Major recent and emerging models for scholarly communication include:

- *The 'Big Deal'* – where institutional subscribers pay for access to online aggregations of titles through consortial or site licensing arrangements (subscription access is also common for research databases);
- *'Author-pays' publishing* – where authors, their employing or funding organisations contribute to the costs of publication; and
- *Open Access archives and repositories* – where organisations support institutional repositories and/or subject archives.

There are also a number of hybrids, such as delayed open access (where journals allow open access after a period during which they are accessible to subscribers only), open choice (where authors can choose to pay author fees and make their works open access, or not to pay and make their works subscription only), and less widespread alternatives, such as pay-per-view (Houghton 2005b, pp57-77).

Figure 1 portrays an evolutionary continuum, highlighting the relationship between changes in scientific publishing business models, the information technology environment, changing research practices and modes of knowledge production – with the ICT infrastructure enabling, and changing research practices demanding, new scholarly communication capabilities and mechanisms.

Figure 1 Evolution of scholarly communication



Source: Author's Analysis.

Enhanced access opportunities

There is evidence of access difficulties and limitations with subscription-based scholarly publishing. In a survey of more than 5,500 senior researchers, Rowlands and Nicholas (2005, p23) found that almost 74% thought that "high prices made it difficult to access the journal literature." Sparks (2005, pp26-28) reported that almost half of the 750 researchers she surveyed reported having problems gaining access to the resources they needed for their research, with more than half in medical and biological sciences (52.5%) and arts and humanities (53.4%)

reporting difficulties. The major reported problems were access to journal articles, books and conference proceedings. Of those reporting difficulties, between 80% and 90% of researchers in medical and biological sciences, physical sciences and social sciences said that their "library did not take the journals they needed to access for their work", as did 70% to 80% of those in languages, arts and humanities. These findings suggest that even for researchers in higher education and specialist research centres in developed countries the subscription-based system creates access limitations.

Such studies are complemented by those outlining the potential benefits of enhanced access. There is an increasing number of studies showing that open access articles are used more, both in terms of citations and downloads (HCSTC 2004, p76; Lawrence 2001; Odlyzko 2002; Prosser 2004; Kurtz 2004; Walker 2004; McVeigh 2004; Brody and Harnad 2004; Harnad *et.al.* 2004; Brody *et.al.* 2005; Getz 2005; Hajjem *et al.* 2005; Davis and Fromerth 2006; etc.). Harboe-Ree (2005) pointed to a number of specific examples: Stevens-Rayburn (2003) noted that *Astrophysical Journal* articles that are also on the pre-print server have a citation rate twice that of papers not on the pre-print server; Antelman (2004) found a significant difference in the mean citation rates of open-access articles and those that are not freely available online, with the relative increase in citations for open-access articles ranging from a low of 45% in philosophy to 51% in electronic and electrical engineering, to 86% in political science and 91% in mathematics; and Harnad and Brody (2004) noted a study of physics articles published each year between 1992 and 2001 revealing a variation on an annual basis of between 2.5 to 5.8 times more citations for open access articles compared to closed access articles.[1]

A number of authors have pointed to the particular benefits of open access for developing countries, where access to the subscription-based literature has often been limited (Chan *et al.* 2005). Awareness of open access is often found to be higher among researchers in developing countries than it is in Western Europe and North America (Rowlands & Nicholas, 2005), and access statistics from open access institutional repositories suggest that researchers from developing countries do use them. For example, during 2005 the ARROW (Australian Research Repositories Online to the World) Discovery Service received hits from 105 domains ('countries'), including 15 from the Dominican Republic, 19 from Armenia, 20 from Egypt, 27 from Zimbabwe, 43 from Belarus, 74 from Latvia, and so on.[2] A similarly broad range of access is revealed in other repository statistics. What is also notable is that the '.com' domain, the generic top level domain for commercial internet users, ranked 5th – even though it includes only generic top level domain commercial registrants and excludes country domain commercial registrants. This suggests that wide dissemination of research is possible through open access.

Exploring the advantages of open access institutional repositories, Pinfield (2004; 2005) noted the potential for greater research impact, the development of innovative overlay services and new forms of analysis. Looking beyond the research community, Getz (2005, pp11-12) noted three important dimensions of benefit: broader industry, government and society impacts; educational impacts; and the potential for greater integration of publications and the other

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1 There is a growing list of such studies reported by The Open Citation Project (http://opcit.eprints.org/oacitation-biblio.html).

2 See http://stats.nla.gov.au/_reports//arrow/yearly/2005/awstats.arrow.html.

digital objects that are increasingly the outputs of research (*e.g.* numeric data sets, software algorithms, animations, sound and video files). He reported a sevenfold increase in use of the MedLine Index following its move to open access, and 30% use by non-professionals, which clearly suggests that there can be significant impact beyond traditional subscription users – evidence, perhaps, of a scholarly communication 'Long Tail' (Anderson 2004).

Kircz (2005) explored the 'dis-benefits' of the subscription publishing system, noting that the published literature was not, as often described, the record of science – at least, not the full record. Firstly, because of timing, it is "*the full stop after the fact*" with current discussion in many fields already based on pre-prints and other communications mechanisms (*e.g.* discussion lists, web logs, etc.). Secondly, because of selectivity in publishing, it is "*only a trophy cabinet*" with little reporting in the formal journal literature of failed experiments, and trial and error tests, etc. The latter was also noted by Gallagher (2005, p8), who suggested that repositories would be "more likely than existing journals to include accessible archives of negative data." These points highlight two important advantages of open access for the efficiency of R&D: *(i)* timeliness and speed of reporting, especially through the posting of pre-prints; and *(ii)* the potential to create a fuller record of science through mandated deposit of findings and other not previously reported materials (*e.g.* field notes or laboratory notes, related data sets, etc.), thus speeding up the research process and avoiding the inefficiency of duplicative research and the pursuit of blind alleys.

Identifying the impacts that might be measured

The potentially measurable impacts of enhanced access to research findings relate to their use by other researchers, industry and government use, and potential use by individuals in the wider community.

Research

The most immediate impacts of enhanced access would be likely to be felt within research, wherein the dimensions of potential impact include:

- Faster access, speeding up the research and discovery process, increasing returns to investment in R&D and, potentially, reducing the time/cost involved for a given outcome and improving the efficiency of R&D;
- Improved access leading to better informed research, reducing the pursuit of blind alleys and reducing duplicative research, saving wasted and duplicative R&D expenditure and improving the efficiency of R&D;
- Wider access both providing enhanced opportunities for multi-disciplinary research, inter-institutional and inter-sectoral collaborations, and enabling researchers to study their context more broadly, potentially leading to increased opportunities for and rates of commercialisation; and
- Greater access leading to improved education outcomes, enabling a given education spend to produce a higher level of educational attainment, leading to an improvement in the capabilities of future researchers and research users.

Industry and government

Given relative levels of access under the subscription publishing system, it is possible that greater potential impacts lie in enhanced access for industry and government users, wherein the dimensions of potential impacts include:

- The potential for wider access to both accelerate and widen opportunities for adoption and commercialisation of research findings, thereby increasing returns on public investment in R&D and on private investment in discovery and commercialisation related activities;
- The potential for much wider access than the subscription publishing system gives for doctors/nurses, teachers/students, small firms in consulting, engineering, architecture, design, electronics/ICTs, biotechnology, nanotechnology, etc., who currently have limited access, with a positive impact on quality of services and, possibly, productivity in both those sectors of the economy and those of their customers and clients; and
- The potential for the emergence of new industries based upon open access content – there are examples of new industries built on publicly accessible data (*e.g.* weather derivatives based on meteorological data), and there are potential futures for publishers to become value adding services providers overlaying open access content (*e.g.* peer review services, bibliometrics and webometrics for research evaluation, etc.), which might, in turn, enhance research evaluation and lead to better focused R&D expenditures.

Impacts might be felt more in particular sectors (*e.g.* knowledge intensive services, biotechnology, etc.). Impacts in such areas as management and economic consulting and engineering might be significant, raising the quality of advice to the benefit of customers and clients across the economy. There may also be positive impacts on policy development, through better informed policy debate and enhanced access to the information underpinning policy decisions. One particularly important dimension might be the potential for greater access for small and medium sized firms (SMEs), enabling SMEs to do more research internally, increasing the share of R&D undertaken by SMEs, and increasing the share of R&D done in industries and countries that include a relatively high share of SMEs.

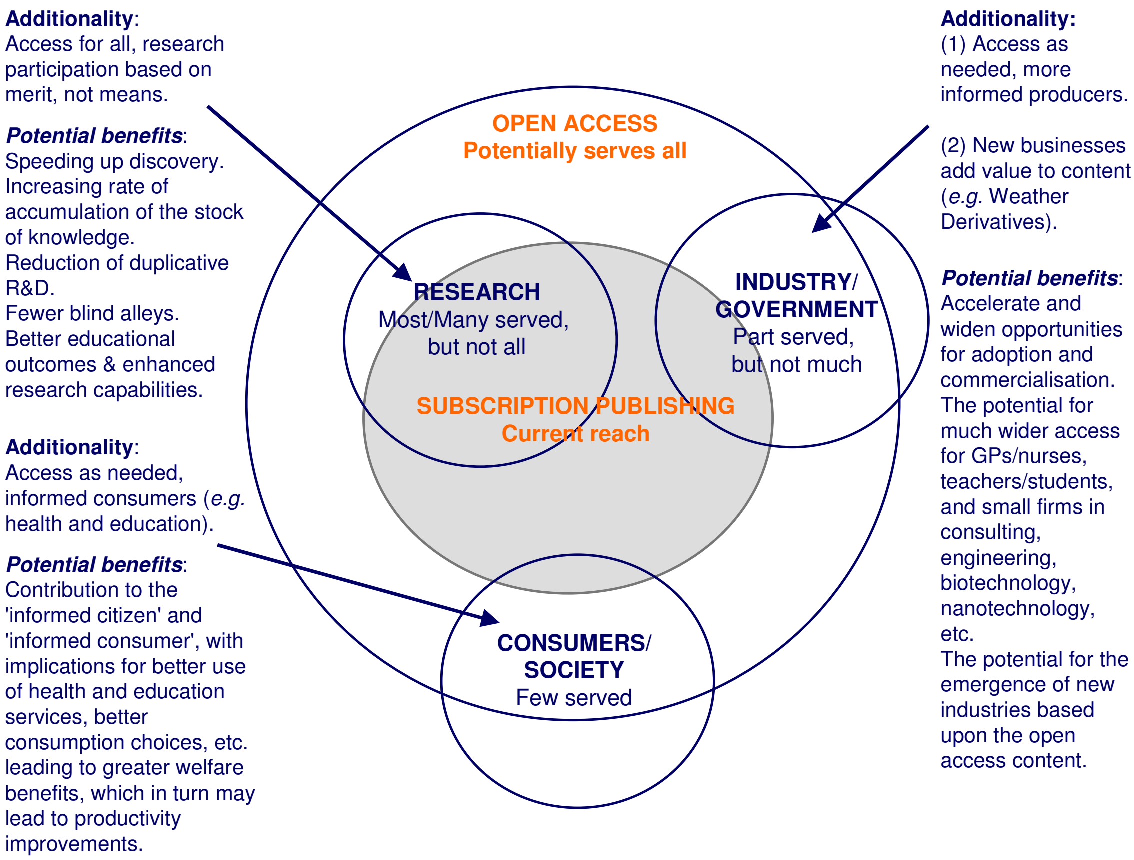
The wider community

In relation to the wider community, the dimensions of potential impact include the potential contribution of open access to the 'informed citizen' and 'informed consumer' – with implications for better use of health and education services, better consumption choices, etc. leading to greater welfare benefits, better health and education outcomes, etc., which may in turn lead to productivity improvements.

An impacts framework

These dimensions of impact are represented in Figure 2, which shows the potential expanded coverage and access available through open access. In the three spheres of activity identified, subscription publishing has served: most, but not all research users; some, but not many industry and government users; and few consumers. The additionality and some of the potential impacts of enhanced access are also shown.

Figure 2 Impact framework: subscription publishing versus open access



Source: Author's Analysis.

Quantifying the impacts of enhanced access

With such a range of potential impacts the task of fully exploring the impacts of enhanced access is substantial. Nevertheless, it is possible to gain some sense of the possible scale of potential impacts by developing a modified growth model, introducing 'access' and 'efficiency' parameters into calculating the returns to R&D. While there are recognised limitations to the traditional growth model approach to estimating returns to R&D (Salter and Martin 2001; Scott *et al.* 2002; Shanks and Zheng 2006), it does provide a basis for preliminary, 'ball park' estimates of the potential impacts of enhanced access.

Returns to R&D in a simple growth model

In the basic Solow-Swan growth model, the key elements are a production function:

(1) $$Y = A^{\eta} K^{\beta} L^{\alpha}$$

where A is an index of technology, K is the capital stock and L is the supply of labour, with both K and L are taken to be fully employed by virtue of the competitive markets assumption, and an accumulation equation:

$$(2) \qquad \dot{K} = sY - \delta K,$$

where $\dot{K}$ is the net investment or the change in the net capital stock, equal to gross investment less depreciation, and δ is a constant depreciation rate. Substituting (1) into (2) gives

$$(3) \qquad \dot{K} = sA^{\eta} K^{\beta} L^{\alpha} - \delta K .$$

From (3) it is possible to determine the conditions for steady state growth in the capital stock.

Re-arranging, taking logarithms, differentiating with respect to time and imposing the condition that for steady state growth:

$$d/dt(\ln \dot{K}/K) = 0$$

gives:

$$(4) \qquad \dot{K}/K = \frac{\eta}{1-\beta} \dot{A}/A + \frac{\alpha}{1-\beta} \dot{L}/L$$

where $\dot{K}/K = \dot{C}/C = \dot{Y}/Y$, is the single constant steady state rate of growth of capital stock, consumption and output, respectively.

The main features of the Solow-Swan model are readily apparent from equation (4). Firstly, if technology and labour supply are fixed, the steady state growth rate is zero. That is, there is no endogenous growth in the model, growth being driven in the steady state by change in the exogenous variables. Secondly, if one of technology and population show positive growth then the steady state growth rate of the economy is proportional to the growth rate in that variable; if both rates are positive the economy's growth rate is a weighted average of the two. Thirdly, the steady state growth rate does not depend upon either the level of savings or of investment in the economy. An economy that continuously saves and invests 20% of national income will have a higher level of output than one investing 5%, but it will not have a higher steady state growth rate. Thus the broad economic message of the Solow-Swan model is that steady growth is possible in a purely competitive world, provided that there is growth in either population or technology, or both.

Contributions to growth and total factor productivity

Solow (1957) further developed this model in a way that provided the foundations for the subsequent "growth accounting industry". Starting with total differentiation of the production function (1), and substituting for the partial derivatives of Y from (1) with respect to each of its arguments, yields:

$$(5) \qquad \dot{Y}/Y = \eta \dot{A}/A + \beta \dot{K}/K + \alpha \dot{L}/L .$$

Equation (5) can then be used in two main ways in the empirical study of growth. Given that in the competitive model capital and labour are paid their marginal products and assuming constant returns to scale, β and α can be estimated from the relative shares of capital and labour. A variant of (5) with those weights can then be used to estimate the relative contribution of capital, labour, technology and other factors to growth. Solow made pioneering estimates in 1957, the results of which he later described as "startling" (Solow 1987), and these have been much refined and amplified by Denison and others (Denison 1985). Solow found that 7/8th of the growth in real output per worker in the US economy between 1909 and 1949 was due to "technical change in the broadest sense" and only 1/8th to capital formation. Denison's 1985 estimates covered the US economy for the period 1929 to 1982. Of the growth in real business output of 3.1% per annum over that period, he found that the increase in labour input with constant educational qualifications accounted for about 25% and capital input for 12%. Most of the remainder is accounted for by technological progress and by the increased human capital of the work-force. What was "startling" about these results was the relatively minor contribution to output growth arising from the increase in the traditional factors of production, capital and labour.

The other related use of equation (5) is to estimate the "Solow residual", or total factor productivity. This is defined as the difference between output growth and the weighted sum of the growth rates of factor inputs (K and L), using constant return to scale weights. That is, total factor productivity growth (TFP) is given by:

$$(6) \qquad TFP = \dot{Y}/Y - \beta\dot{K}/K - \alpha\dot{L}/L \, ,$$

where $\beta = 1 - \alpha$, and β and α are derived from the shares of capital and labour in total income.

Total factor productivity is thus the growth in output not accounted for, on these assumptions, by the growth in capital and labour inputs. This method is now used very widely around the world in measuring productivity. This recent use has confirmed the broad Solow-Denison findings, in that for most modern economies total factor productivity growth is significantly more important than expansion of inputs in explaining total output growth. However, it must be remembered that the method rests on the assumptions embedded in the Solow model and that, as a consequence, the finding that the larger proportion of growth is to be explained by an exogenous "technical change in the broadest sense" constitutes something of an admission of defeat for economic analysis.

Estimating the rate of return to R&D

This basic framework has been widely used in estimating the rate of return to R&D. A characteristic finding is that the social returns to R&D are high (in the region of 30-60%, and higher in some cases) (Industry Commission 1995; Salter and Martin 2001; Scott *et al.* 2002; Dowrick 2003; Shanks and Zheng 2006). While there is considerable variation in the rates of return reported in studies around the world, these rates are indicative (Table 1). Coe and Helpman (1993), Jones and Williams (1998) and others have shown that similar rates of return arise from endogenous growth models. Moreover, champions of the evolutionary approach suggest that, limited to seeing new knowledge as the output of research, simple growth models do not include other forms of economic benefit (*e.g.* skills development, development of instrumentation, development of networks, etc.) (Salter and Martin 2001; Scott *et al.* 2002). To the extent that these dimensions of impact are not in fact accounted for in simple growth models, the impacts may be even greater than those models show.

Table 1 Estimates of private and social rates of return to private R&D

Study	*Private rate of return (%)*	*Social rate of return (%)*
Minnasian (1962)	25	..
Nadiri (1993)	20-30	50
Mansfield (1977)	25	56
Terleckyj (1974)	27	48-78
Sveikauskas (1981)	10-23	50
Goto & Suzuki (1989)	26	80
Mohnen & Lepine (1988)	56	28
Bernstein & Nadiri (1988)	9-27	10-160
Scherer (1982, 1984)	29-43	64-147
Bernstein & Nadiri (1991)	14-28	20-110

Source: Salter & Martin 2001, p514.

The standard approach to estimation of returns to R&D is to divide the technology variable A in (1) into two components, a stock of R&D knowledge variable R and a variable Z that represents a matrix of other factors affecting productivity growth. The production function then becomes:

$$(6) \qquad Y = K^{\alpha} L^{\beta} R^{\gamma} Z^{\eta},$$

and the counterpart of equation (5) becomes:

$$(7) \qquad \dot{Y}/Y = \alpha\, \dot{K}/K + \beta\, \dot{L}/L + \gamma\, \dot{R}/R + \eta\, \dot{Z}/Z.$$

That is, the rate of growth of the R&D knowledge stock (*i.e.* accumulated R&D expenditure or R&D capital) contributes to output growth as a factor of production, with elasticity γ. The rate of return to knowledge ($\partial y/\partial R$) is that continuing average per cent increment in output resulting from a one per cent increase in the knowledge stock. This can be readily derived from the elasticity γ by

$$(8) \qquad \partial y/\partial R = \gamma . (Y/R).$$

The normal approach to creating a measure of the stock of R&D knowledge, for a given industry or for the economy as a whole, is to use the perpetual inventory method to create the knowledge stock from the flows of R&D, using the relationship:

$$(9) \qquad R_t = (1 - \delta)\, R_{t-1} + R\&D_{t-1},$$

where δ is the rate of obsolescence of the knowledge stock. This method also requires some starting estimates (R_0) of the knowledge stock, and estimates can be sensitive to that assumption. Then the capital stock at time *t* is given by:

$$(10) \qquad R_t = (1 - \delta)^t R_0 + \sum_{i=0}^{t-1} (1 - \delta)^I R\&D_{t-1}$$

Given a series for R and for the variables Z, it is then possible to estimate γ by either of the two methods noted above: estimate equation (7) with the parameters α .. η unconstrained, or obtain estimates of the parameters α and β (constrained to be equal to one) from the factor shares of capital and labour, calculate TFP by a variant of (6) and regress R and Z on TFP to obtain γ.

Incorporating the efficiency of R&D and accessibility of knowledge

This standard approach makes some key assumptions. Here we note three in particular. It is assumed that:

- All R&D generates knowledge that is useful in economic or social terms (*efficiency of R&D*);
- All knowledge is equally accessible to all firms or other entities that could make productive use of it (*accessibility of knowledge*); and
- All types of knowledge are equally substitutable across firms and uses (*substitutability*).

A good deal of work has been done to address the fact that the substitutability assumption is not realistic, as particular types of knowledge are often specialised to particular industries and applications. Much less has been done on the other two assumptions, which are our focus.

We define an 'accessibility' parameter ε as the proportion of the R&D knowledge stock that is accessible to those who could use it productively, and an 'efficiency' of R&D parameter ϕ as the proportion of R&D spending that generates useful knowledge. Then starting with a given stock of useful knowledge R^*_0 at the start of period zero, useful knowledge at the start of period 1 will be given by:

$$(10) \qquad R^*_1 = (1 - \delta)\, R^*_0 + \phi\, R\&D_0,$$

where the contribution of R&D in period zero to the knowledge stock is reduced by the parameter ϕ to allow for unproductive R&D. This means that the stock of useful knowledge at period *t* is given by:

$$(11) \qquad R^*_t = (1 - \delta)^t R^*_0 + \phi \sum_{i=0}^{t-1} (1 - \delta)^i\, R\&D_{t-1}$$

If the period over which knowledge is accumulated is long, so that $(1 - \delta)^t R^*_0$ is small relative to R^*_t, then R^*_t can be approximated by ϕR. However, only a proportion of useful knowledge may be accessible, so that accessible useful knowledge at period *t* is εR^*_t, and hence approximately $\phi\varepsilon R_t$, where R_t is the stock of knowledge as calculated under the standard methods.

Using this approximation and noting that it is accessible useful knowledge that is the correct factor in the production function, (6) becomes:

$$(11) \qquad Y = K^\alpha L^\beta (\phi\varepsilon R)^\gamma Z^\eta$$

If ϕ and ε are independent functions of time, then the results of estimating a linearised version of (11) that excludes them will be misleading. However, if we assume that these parameters reflect institutional structures for research and research commercialisation in a given country, and can hence be taken as fixed (and as less than or equal to one), then the standard results stand, but need to be reinterpreted. Again using R as the stock of knowledge calculated by the standard method (which assumes $\phi = \varepsilon = 1$) and R^* as the corresponding accessible stock of useful knowledge, then $R = R^*/\phi\varepsilon$, and the rate of return to useful and accessible knowledge becomes:

$$(12) \qquad \partial y/\partial R^* = \gamma.\,(Y/R^*) = \gamma/\phi\varepsilon.\,(Y/R) = \gamma.\,(Y/R).1/\phi\varepsilon.$$

Thus, if ϕ and/or ε are less than one, the rate of return to R^* is greater than that to R by the factor $1/\phi\varepsilon$. This does not imply that the measured rate of return to R is biased, because $R^* = \phi\varepsilon R$.

Assume now that there is a one-off increase in the value of ϕ and ε, from the constant values of ϕ_0 and ε_0 to new values of $(1 + \delta_\phi)\phi_0$ and $(1 + \delta_\varepsilon)\varepsilon_0$, respectively. Then the rate of return to R^*, that is:

$$(12) \qquad \partial y/\partial R^* = \gamma.\,(Y/R).\,(1/\phi_0\varepsilon_0)$$

is fixed, but the return to R will increase:

$$(13) \qquad \partial y/\partial R = \gamma.\,(Y/R) = \phi_1\varepsilon_1\,\partial y/\partial R^* = \gamma.\,(Y/R).\,(\phi_1\varepsilon_1\,/\phi_0\varepsilon_0)$$

$$= \gamma.\,(Y/R).\,(1 + \delta_\phi).(1 + \delta_\varepsilon)\varepsilon_0.$$

It follows from (13) that, because the increase in efficiency and accessibility leads to a higher value of R^* for a given level of R, the rate of return to R will increase by the compound rate of increase of the percentage changes in ϕ and ε.

Estimating the impacts of a one-off increase in accessibility and efficiency

The basic result of the foregoing is that, if ‘accessibility’ and ‘efficiency’ are constant over the estimation period but then show a one-off increase (*e.g.* because of a move to open access) then, to a close approximation, the return to R&D will increase by the same percentage increase as that in the accessibility and efficiency parameters.

Table 2 shows the recurring annual gain from a given percentage change in both accessibility and efficiency for gross expenditure on R&D (GERD) and government expenditure on R&D (GovERD) for all OECD countries. It presents impact ranges based on rates of return to R&D of 25% to 75% and 1% to 10% increases in accessibility and efficiency in USD PPPs (current prices). It assumes, for illustrative purposes only, that the increase in both parameters is the same, and that the change (*e.g.* to open access) has no *net* impact on the rates of accumulation or obsolescence of the stock of knowledge. This latter assumption is clearly one to be revisited in further work.

Consistent with Solow’s original findings, the literature that estimates high rates of return to R&D implies that the contribution of R&D to output in a modern economy is high. Given this fact, the results above imply that, if a move to open access has a significant beneficial impact on either or both the accessibility or efficiency of R&D, then the benefits of open access will be high also. Assuming, for example, that a move towards open access increased access and efficiency by 5% and that the social rate of return to GERD was 50%, then if there had been open access to all OECD research circa 2003 it would have increased the social returns to R&D by some USD 36 billion. These are recurring annual gains from the effect on one year’s R&D. Hence, assuming that the change is permanent, they can be converted to growth rate effects.

Table 2 Estimates of impacts of a one-off increase in accessibility and efficiency (USD PPPs)

GERD

Australia 9,609	Return to R&D				
Per cent change in accessibility and efficiency	25%	40%	50%	60%	75%
	Recurring annual gain from move to open access (USDm PPPs)				
1%	48	77	97	116	145
2%	97	155	194	233	291
5%	246	394	492	591	739
10%	504	807	1,009	1,211	1,513

Austria 6,371	Return to R&D				
Per cent change in accessibility and efficiency	25%	40%	50%	60%	75%
	Recurring annual gain from move to open access (USDm PPPs)				
1%	32	51	64	77	96
2%	64	103	129	154	193
5%	163	261	327	392	490
10%	334	535	669	803	1,003

Belgium 5,803	Return to R&D				
Per cent change in accessibility and efficiency	25%	40%	50%	60%	75%
	Recurring annual gain from move to open access (USDm PPPs)				
1%	29	47	58	70	87
2%	59	94	117	141	176
5%	149	238	297	357	446
10%	305	487	609	731	914

GovERD

Australia 1,857	Return to R&D				
Per cent change in accessibility and efficiency	25%	40%	50%	60%	75%
	Recurring annual gain from move to open access (USDm PPPs)				
1%	9	15	19	22	28
2%	19	30	38	45	56
5%	48	76	95	114	143
10%	97	156	195	234	292

Austria 292	Return to R&D				
Per cent change in accessibility and efficiency	25%	40%	50%	60%	75%
	Recurring annual gain from move to open access (USDm PPPs)				
1%	1	2	3	4	4
2%	3	5	6	7	9
5%	7	12	15	18	22
10%	15	25	31	37	46

Belgium 396	Return to R&D				
Per cent change in accessibility and efficiency	25%	40%	50%	60%	75%
	Recurring annual gain from move to open access (USDm PPPs)				
1%	2	3	4	5	6
2%	4	6	8	10	12
5%	10	16	20	24	30
10%	21	33	42	50	62

Canada	Return to R&D				
19,326	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	97	155	194	233	291
2%	195	312	390	468	586
5%	495	792	990	1,189	1,486
10%	1,015	1,623	2,029	2,435	3,044

Czech Rep.	Return to R&D				
2,406	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	12	19	24	29	36
2%	24	39	49	58	73
5%	62	99	123	148	185
10%	126	202	253	303	379

Denmark	Return to R&D				
4,374	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	22	35	44	53	66
2%	44	71	88	106	133
5%	112	179	224	269	336
10%	230	367	459	551	689

Canada	Return to R&D				
2,024	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	10	16	20	24	31
2%	20	33	41	49	61
5%	52	83	104	124	156
10%	106	170	212	255	319

Czech Rep.	Return to R&D				
509	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	3	4	5	6	8
2%	5	8	10	12	15
5%	13	21	26	31	39
10%	27	43	53	64	80

Denmark	Return to R&D				
298	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	1	2	3	4	4
2%	3	5	6	7	9
5%	8	12	15	18	23
10%	16	25	31	38	47

Finland	Return to R&D				
5,205	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	26	42	52	63	78
2%	53	84	105	126	158
5%	133	213	267	320	400
10%	273	437	547	656	820

Finland	Return to R&D				
505	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	3	4	5	6	8
2%	5	8	10	12	15
5%	13	21	26	31	39
10%	26	42	53	64	79

France	Return to R&D				
39,740	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	200	320	399	479	599
2%	401	642	803	963	1,204
5%	1,018	1,629	2,037	2,444	3,055
10%	2,086	3,338	4,173	5,007	6,259

France	Return to R&D				
6,640	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	33	53	67	80	100
2%	67	107	134	161	201
5%	170	272	340	408	510
10%	349	558	697	837	1,046

Germany	Return to R&D				
58,688	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	295	472	590	708	885
2%	593	948	1,185	1,423	1,778
5%	1,504	2,406	3,008	3,609	4,512
10%	3,081	4,930	6,162	7,395	9,243

Germany	Return to R&D				
7,775	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	39	63	78	94	117
2%	79	126	157	188	236
5%	199	319	398	478	598
10%	408	653	816	980	1,225

Greece	Return to R&D				
1,392	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	7	11	14	17	21
2%	14	22	28	34	42
5%	36	57	71	86	107
10%	73	117	146	175	219

Greece	Return to R&D				
291	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	1	2	3	4	4
2%	3	5	6	7	9
5%	7	12	15	18	22
10%	15	24	31	37	46

Hungary	Return to R&D				
1,424	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	7	11	14	17	21
2%	14	23	29	35	43
5%	37	58	73	88	110
10%	75	120	150	179	224

Hungary	Return to R&D				
425	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	2	3	4	5	6
2%	4	7	9	10	13
5%	11	17	22	26	33
10%	22	36	45	54	67

Iceland	Return to R&D				
253	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	1	2	3	3	4
2%	3	4	5	6	8
5%	6	10	13	16	19
10%	13	21	27	32	40

Iceland	Return to R&D				
63	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	0	1	1	1	1
2%	1	1	1	2	2
5%	2	3	3	4	5
10%	3	5	7	8	10

Ireland	Return to R&D				
1,762	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	9	14	18	21	27
2%	18	28	36	43	53
5%	45	72	90	108	135
10%	92	148	185	222	277

Ireland	Return to R&D				
134	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	1	1	1	2	2
2%	1	2	3	3	4
5%	3	5	7	8	10
10%	7	11	14	17	21

Italy	Return to R&D				
17,699	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	89	142	178	213	267
2%	179	286	358	429	536
5%	454	726	907	1,088	1,361
10%	929	1,487	1,858	2,230	2,788

Italy	Return to R&D				
3,259	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	16	26	33	39	49
2%	33	53	66	79	99
5%	84	134	167	200	251
10%	171	274	342	411	513

Japan	Return to R&D				
112,715	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	566	906	1,133	1,359	1,699
2%	1,138	1,821	2,277	2,732	3,415
5%	2,888	4,621	5,777	6,932	8,665
10%	5,918	9,468	11,835	14,202	17,753

Japan	Return to R&D				
10,494	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	53	84	105	127	158
2%	106	170	212	254	318
5%	269	430	538	645	807
10%	551	881	1,102	1,322	1,653

Korea	Return to R&D				
24,274	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	122	195	244	293	366
2%	245	392	490	588	735
5%	622	995	1,244	1,493	1,866
10%	1,274	2,039	2,549	3,058	3,823

Korea	Return to R&D				
3,056	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	15	25	31	37	46
2%	31	49	62	74	93
5%	78	125	157	188	235
10%	160	257	321	385	481

Luxembourg	Return to R&D				
432	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	2	3	4	5	7
2%	4	7	9	10	13
5%	11	18	22	27	33
10%	23	36	45	54	68

Luxembourg	Return to R&D				
46	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	0	0	0	1	1
2%	0	1	1	1	1
5%	1	2	2	3	4
10%	2	4	5	6	7

Mexico	Return to R&D				
3,625	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	18	29	36	44	55
2%	37	59	73	88	110
5%	93	149	186	223	279
10%	190	304	381	457	571

Mexico	Return to R&D				
1,416	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	7	11	14	17	21
2%	14	23	29	34	43
5%	36	58	73	87	109
10%	74	119	149	178	223

Netherlands	Return to R&D				
9,103	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	46	73	91	110	137
2%	92	147	184	221	276
5%	233	373	467	560	700
10%	478	765	956	1,147	1,434

New Zealand	Return to R&D				
1,085	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	5	9	11	13	16
2%	11	18	22	26	33
5%	28	44	56	67	83
10%	57	91	114	137	171

Norway	Return to R&D				
2,961	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	15	24	30	36	45
2%	30	48	60	72	90
5%	76	121	152	182	228
10%	155	249	311	373	466

Netherlands	Return to R&D				
1,318	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	7	11	13	16	20
2%	13	21	27	32	40
5%	34	54	68	81	101
10%	69	111	138	166	208

New Zealand	Return to R&D				
314	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	2	3	3	4	5
2%	3	5	6	8	10
5%	8	13	16	19	24
10%	16	26	33	40	49

Norway	Return to R&D				
447	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	2	4	4	5	7
2%	5	7	9	11	14
5%	11	18	23	27	34
10%	23	38	47	56	70

Poland	Return to R&D				
2,472	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	12	20	25	30	37
2%	25	40	50	60	75
5%	63	101	127	152	190
10%	130	208	260	311	389

Poland	Return to R&D				
1,005	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	5	8	10	12	15
2%	10	16	20	24	30
5%	26	41	52	62	77
10%	53	84	106	127	158

Portugal	Return to R&D				
1,533	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	8	12	15	18	23
2%	15	25	31	37	46
5%	39	63	79	94	118
10%	80	129	161	193	241

Portugal	Return to R&D				
259	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	1	2	3	3	4
2%	3	4	5	6	8
5%	7	11	13	16	20
10%	14	22	27	33	41

Slovakia	Return to R&D				
405	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	2	3	4	5	6
2%	4	7	8	10	12
5%	10	17	21	25	31
10%	21	34	42	51	64

Slovakia	Return to R&D				
123	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	1	1	1	1	2
2%	1	2	2	3	4
5%	3	5	6	8	9
10%	6	10	13	16	19

Spain	Return to R&D				
11,072	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	56	89	111	134	167
2%	112	179	224	268	335
5%	284	454	567	681	851
10%	581	930	1,163	1,395	1,744

Spain	Return to R&D				
1,701	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	9	14	17	21	26
2%	17	27	34	41	52
5%	44	70	87	105	131
10%	89	143	179	214	268

Sweden	Return to R&D				
10,340	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	52	83	104	125	156
2%	104	167	209	251	313
5%	265	424	530	636	795
10%	543	869	1,086	1,303	1,629

Sweden	Return to R&D				
360	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	2	3	4	4	5
2%	4	6	7	9	11
5%	9	15	18	22	28
10%	19	30	38	45	57

Switzerland	Return to R&D				
5,627	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	28	45	57	68	85
2%	57	91	114	136	171
5%	144	231	288	346	433
10%	295	473	591	709	886

Switzerland	Return to R&D				
79	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	0	1	1	1	1
2%	1	1	2	2	2
5%	2	3	4	5	6
10%	4	7	8	10	12

Turkey	Return to R&D				
3,014	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	15	24	30	36	45
2%	30	49	61	73	91
5%	77	124	154	185	232
10%	158	253	317	380	475

UK	Return to R&D				
33,706	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	169	271	339	406	508
2%	340	545	681	817	1,021
5%	864	1,382	1,727	2,073	2,591
10%	1,770	2,831	3,539	4,247	5,309

US	Return to R&D				
312,535	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	1,570	2,513	3,141	3,769	4,711
2%	3,157	5,051	6,313	7,576	9,470
5%	8,009	12,814	16,017	19,221	24,026
10%	16,408	26,253	32,816	39,379	49,224

Turkey	Return to R&D				
211	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	1	2	2	3	3
2%	2	3	4	5	6
5%	5	9	11	13	16
10%	11	18	22	27	33

UK	Return to R&D				
3,255	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	16	26	33	39	49
2%	33	53	66	79	99
5%	83	133	167	200	250
10%	171	273	342	410	513

US	Return to R&D				
38,128	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency	Recurring annual gain from move to open access (USDm PPPs)				
1%	192	307	383	460	575
2%	385	616	770	924	1,155
5%	977	1,563	1,954	2,345	2,931
10%	2,002	3,203	4,003	4,804	6,005

OECD	Return to R&D				
708,949	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency					
	Recurring annual gain from move to open access (USDm PPPs)				
1%	3,562	5,700	7,125	8,550	10,687
2%	7,160	11,457	14,321	17,185	21,481
5%	18,167	29,067	*36,334*	43,600	54,500
10%	37,220	59,552	74,440	89,328	111,659

OECD	Return to R&D				
86,680	25%	40%	50%	60%	75%
Per cent change in accessibility and efficiency					
	Recurring annual gain from move to open access (USDm PPPs)				
1%	436	697	871	1,045	1,307
2%	875	1,401	1,751	2,101	2,626
5%	*2,221*	3,554	4,442	5,331	6,664
10%	4,551	7,281	9,101	10,922	13,652

Note: R&D expenditure data are taken from OECD (2006) *Main Science and Technology Indicators 2005*, OECD, Paris. Available from SourceOECD. They are presented in USD PPPs, current prices, and relate to the most recent data available for each country (typically 2002-2003). The OECD total is the simple sum of the available country expenditures.
Source: OECD, Authors' analysis.

The potential impacts of enhanced access

Whether applied across the board or to sector specific research findings (*e.g.* open access to publicly funded research) it seems that there may be substantial potential benefits to be gained from more open access. For example, reading from Table 2 (above), circa 2003:

- With Germany's GERD at USD 58.7 billion and assuming social returns to R&D of 50%, a 5% increase in access and efficiency would have been worth USD 3 billion;
- With Japan's GERD at USD 112.7 billion and assuming social returns to R&D of 50%, a 5% increase in access and efficiency would have been worth USD 5.8 billion;
- With the United Kingdom's GERD at USD 33.7 billion and assuming social returns to R&D of 50%, a 5% increase in access and efficiency would have been worth USD 1.7 billion; and
- With the United State's GERD at USD 312.5 billion and assuming social returns to R&D of 50%, a 5% increase in access and efficiency would have been worth USD 16 billion.

While it is impossible to calculate the quantum of benefits with certainty, these simple estimates of the potential impacts of enhanced access on returns to R&D suggest that a move towards more open access may have substantial positive impacts.

Conclusions and developments

There are two main conclusions to this paper. One is that, while there are many limitations to the approach outlined, these simple estimates provide some sense of the possible scale of the potential impacts of enhanced access on returns to R&D. The second is that the returns to R&D approach, with accessibility and efficiency parameters, offers the foundation for one method for measuring these impacts in a more rigorous manner. These estimates might be refined with further research on such issues as:

- Developing estimates of the contribution of publications and other potentially open access digital objects to the stock of knowledge generated by R&D (*e.g.* estimating what proportion of the stock of knowledge might be affected by open access);
- Finding direct measurable links between access, use and efficiency, to enable estimation of the appropriate percentage change to apply to the accessibility and efficiency variables (*e.g.* direct links between access, downloads and citations, and access and levels of duplication, etc.);
- Finding measures of the use of subscription-based and open access content by non-research users (*e.g.* users in industry, government, non-government organisations and the wider community);
- Exploring the extent of 'leakage' of impacts across national borders, to better understand where benefits may accrue and the potential importance of international initiatives towards open access;

- Exploring the impacts of enhanced access to different R&D categories (*e.g.* Gross Expenditure on R&D, Government Expenditure on R&D, Higher Education R&D Expenditure, etc.) using appropriate rates of returns for each category;
- Exploring various national data using ‘local’ rates of return to R&D reported in national studies;
- Further examining the potential impacts of a one-off change to enhanced access on the accumulation and obsolescence of the stock of R&D knowledge, and exploring the impacts of applying different rates ‘depreciation’;
- Exploring marginal as well as average rates of return, and the potential impacts of increases in accessibility and efficiency on marginal returns to R&D (*e.g.* under what circumstances are various categories of R&D facing increasing or decreasing returns); and
- Examining the extent to which the ‘non-informational’ benefits of R&D cited by proponents of the evolutionary approach (*e.g.* Salter and Martin 2001; Scott *et al.* 2002) do in fact fall outside the scope of such growth models.

Given substantial R&D expenditures and the scale of the potential impacts identified in this preliminary work, these issues represent fertile ground for further policy relevant inquiry.

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